Awwa Research Foundation
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EPA

Case Study for a Distribution System Emergency Response Tool

Project #2922
Subject Area:
Efficient and Customer-Responsive Organization

Case Study for a Distribution System Emergency Response Tool

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Case Study for a Distribution System Emergency Response Tool

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FOREWORD

The Awwa Research Foundation is a nonprofit corporation that is dedicated to the implementation of a research effort to help utilities respond to regulatory requirements and traditional high-priority concerns of the industry. The research agenda is developed through a process of grass-roots consultation with subscribers, members, and working professionals. Under the umbrella of a Strategic Research Plan, the Research Advisory Council prioritized the suggested projects based upon current and future needs, applicability, and past work; the recommendations are forwarded to the Board of Trustees for final selection. The foundation also sponsors research projects through the unsolicited proposal process; the Collaborative Research, Research Applications, and Tailored Collaboration programs; and various joint research efforts with organizations such as the U.S. Environmental Protection Agency, the U.S. Bureau of Reclamation, and the Association of California Water Agencies.

This publication is a result of one of those sponsored studies, and it is hoped that its findings will be applied in communities throughout the world. The following report serves not only as a means of communicating the results of the water industry's centralized research program but also as a tool to enlist the further support of the nonmember utilities and individuals.

Projects are managed closely from their inception to the final report by the foundation's staff and large cadre of volunteers who willingly contribute their time and expertise. The foundation serves as a planning and management function and awards contracts to other institutions such as water utilities, universities, and engineering firms. The funding for this research effort comes primarily from the Subscription Program, through which water utilities subscribe to the research program and make an annual payment proportionate to the volume of water they deliver and consultants subscribe based on their annual billings. The program offers a cost-effective and fair method for funding research in the public interest.

A broad spectrum of water supply issues is addressed by the foundation's research agenda: resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide the highest possible quality of water economically and reliably. The true benefits are realized when the results are implemented at the utility level. The foundation's trustees are pleased to offer this publication as a contribution toward that end.

Monitoring and/or predicting the fate and transport of introduced contaminants in water distribution systems is a challenging proposition, involving the identification and operationalization of numerous hydrological and water quality-related factors. A common and important question in the design of a monitoring network is how many samples should be collected and where? The answer is often based upon the best professional judgment of system personnel and financial considerations. The best answer will be based on an objective approach, dependent on a number of factors, including the desired statistical power and level of confidence in the final decision and the variability of the environmental attribute of interest. This report describes a methodology that can be used for determining optimal placement of extraction and monitoring instruments, and/or to predict/track the fate and transport of contaminants in a system in order to effectively respond to a purposeful contamination incident as well as accidental events such as backflow or cross connections.

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EXECUTIVE SUMMARY

Water distribution systems are hyper complex structures, distinguished by extreme pressure gradients, spatial extensiveness, and other physical-hydrological variables. Monitoring and/or predicting the fate and transport of introduced contaminants in water distribution systems is therefore a challenging proposition, involving the identification and operationalization of numerous hydrological and water quality-related factors. The availability of a water distribution system model for emergency response and/or security purposes would allow water utilities to identify, monitor, and track contaminants in their water distribution system and to react more quickly to a terrorism incident.

RESEARCH OBJECTIVES

The objectives of this project are to evaluate the feasibility of using the PipelineNet water distribution system model in different water utility settings and to make any needed recommendations for upgrading this model. PipelineNet monitors and projects the fate and transport of potentially introduced contaminants in water distribution systems, particularly as related to use and application in an emergency response situation. It can be used for determining optimal placement of extraction and monitoring instruments, to help develop monitoring regimes for routine screening of distribution system water quality, and/or to predict/track the fate and transport of contaminants in a system in order to effectively respond to a purposeful contamination incident as well as accidental events such as backflow or cross connections.

APPROACH

The project approach was to develop a fully calibrated extended period simulation model for the East Bay Municipal Utility District (EBMUD) using PipelineNet. This EBMUD model was used as a case study for developing a methodology for locating monitoring stations in the distribution system. This methodology uses a hierarchical selection process and employs a stepwise approach based on model inputs, outputs and GIS layers. Initially, all the elements of the water distribution system are available for monitoring. This universe is reduced to a smaller set based on priorities set by a water utility. These priorities may include physically accessible nodes, definition of priority areas based on flow, velocity, pressure and water quality, and proximity to critical facilities (i.e., schools and hospitals).

Among the specific issues to be addressed are: (1) location of monitoring points in the distribution system, (2) timing and frequency of monitoring, and (3) monitoring techniques and water quality parameters.

CONCLUSIONS

PipelineNet was originally developed to support emergency response for the Salt Lake City Winter Olympics. In this study the following features were developed that will help water utilities to meet its normal operations and also to respond to intentional contamination:

1. EPANET hydraulic model - includes all the functionality of EPANET and GIS
2. GIS based system – allows for geo-features and map display with an overlay of model output
3. Ranking/prioritization Tool - assists in the location of monitoring stations
4. Consequence Assessment Tool – calculates population and infrastructure at risk from an event
5. Isolation Tool – evaluate the effectiveness of mitigation measures to reduce the spread of contamination (closing pipes)
6. Spatial Display Database Tool – helps in regulatory compliance as described in Stage 2 Disinfectants and Disinfections Byproducts Rule: Initial Distribution System Evaluation (IDSE) Guidance
7. Normal Operation – simulates hydraulics (flow) and water quality (concentration, tracing, and ageing)
8. Emergency Response and Planning – simulates water quality for chemical and biological agents (includes the growth and decay of biological agents, the decay of chemical agents; and reactions with other constituents, i.e., chlorine)

PipelineNet is a user-friendly system. It requires knowledge of hydraulic modeling and basic GIS functions. The development of a PipelineNet application involves the following steps:

- Convert steady state model to EPS model
- Perform calibration on integrated EPS model
- Load utility specific EPANET input file into PipelineNet
- Populate PipelineNet with utility specific GIS data
- Run scenarios
- Evaluate results

The time and effort needed to get PipelineNet up and running is dependent on the condition and status of a utility's hydraulic model and GIS data. If these two components are fully developed, then the PipelineNet application can be made operational in a short time frame (3-6 months). Additional time and effort is required if the model is not fully developed and GIS data needs to be produced.

FUTURE RESEARCH AND RECOMMENDATIONS

PipelineNet is a versatile emergency response model that also has applicability for normal operations. To meet the future needs of water utilities, the following six recommendations are presented. The PipelineNet model is modular in design, thus the capabilities described below could be incorporated into the system through its current framework.

1. *Contaminant database* – New sources of information on the physical-chemical-biological properties of contaminants (e.g., EPA State of Knowledge Report and Lawrence Livermore National Laboratory Project) are being developed. When this data is available, it should be incorporated into PipelineNet so that water utilities are better informed.

2. *Back tracing* - Back tracing identifies source(s) of contamination once a monitoring station located within the distribution system detects them. It helps in responding to a deliberate or accidental release by identifying the area and display of water flows from single/multiple points to the monitoring location
3. *Time of travel* – This calculation will help in identifying the time for the leading edge, peak concentration and trailing edge of a contaminant plume to reach any node in the system. This information would allow a warning to be issued to a critical facility or service sub-area about the arrival time of the contaminant.
4. *Decontamination* - The two primary elements of clean up and decontamination are treatment of the contaminated pipelines and disposal of the contaminated water. Development of a database of technologies to clean chem-bio agents in contaminated water and identification of disposal methods for the contaminated water would be very useful response information that could be incorporated into PipelineNet.
5. *Conversion from ARCVIEW 3.2 to ARCGIS* - The current version of PipelineNet is based on ARCVIEW 3.2; however, many water utilities are upgrading to ARCGIS and adopting the ARC FM WATER data model. The conversion of PipelineNet to ARCGIS and the ARC FM WATER data model will keep it current with the evolution of GIS technology.
6. *Linkage of PipelineNet to SCADA Data* – Linking PipelineNet with a utility's SCADA system allows real-time updates of the hydraulic model's input conditions (i.e., tank levels and demand patterns).

CHAPTER 1: INTRODUCTION

The need for modeling software, for use in responding to malevolent contamination of distribution systems, was discussed at a security research-planning meeting held by AwwaRF on May 21 and 22, 2002. The premise of these discussions was that there were no programs available that were adequate to address the needs of the water community, and such a program needed to be developed. In later discussions it was pointed out that PipelineNet seemed to address most of the needs of the water community but there were concerns as to whether the program could easily be made operative at cities other than where it was originally used. The decision was made in the summer 2002, to investigate through a case study, if PipelineNet was sufficient to address the stated needs of the water community, or if new functionalities of PipelineNet were needed. Thus, in late 2002 this project started as an AwwaRF/USEPA project.

OBJECTIVES

The objectives of this project are to evaluate the feasibility of using the PipelineNet water distribution system model in different water utility settings and to make any needed recommendations for upgrading this model. The case study used in this application of PipelineNet addresses three specific tasks:

Task 1 - Location of monitoring points in the distribution system. Appropriate monitoring location selection should reflect a mix of utility concerns and priorities including:

- Protecting critical customers (e.g., hospitals)
- Tracking water quality at or near locations vulnerable to contamination
- Facilitating suitable responses to contamination incidents (e.g., ability to isolate the system, or boost chlorine residuals, etc.)

Task 2 - Timing and frequency of monitoring. Timing and frequency will depend on several key factors, and should include variations that cover:

- The intent to perform routine screening of distribution system water quality parameters
- The intent to develop a suitable response to a suspected or known contamination incident in the network (e.g., trying to isolate the contaminant and then decontaminate the system). In the latter applications, models will need to account for the timing and duration of peaks, valleys and other variabilities in contaminant concentrations that may occur spatially and temporally throughout a distribution system.

Task 3- Monitoring techniques and water quality parameters. Among the research issues to be addressed are:

- Defining what water quality parameters should be tracked;
- Knowing how to interpret levels or changes in key water quality parameters; and
- What sampling procedures, monitoring devices, and analytic methods to employ to identify these changes.

BACKGROUND

Each distribution system has unique features, and each potential contaminant has its own properties as well. Because of the uniqueness of the system and the contaminant, the monitoring program within a distribution system is specific to its operation. The monitoring information for each of the contaminant categories is obtained specifically for the needs of that particular category.

A common and important question in the design of a monitoring network is how many samples should be collected and where (location and frequency)? The frequency involves how often a sample is taken. In case of routine monitoring the frequency is guided by the regulations. But in case of a contamination event (intentional or accidental), the frequency needs to be defined based on the flow of the contaminant in the system at different times. Chemical-biological agents do not come under any monitoring regulations. The answer is often based upon resource availability and the best professional judgment of system personnel. The best answer will be based on an objective approach, dependent on a number of factors, including the desired statistical power and level of confidence in the final decision and the variability of the environmental attribute of interest.

Several researchers have developed hydraulic models for water distribution. In 1999, SAIC under contract to the Technical Support Working Group (TSWG) developed a GIS based water distribution model, PipelineNet, for application during the Salt Lake City Olympics in early 2002 (Samuels and Bahadur 2001). The PipelineNet system was further developed with additional functionality for potential purposeful contamination events with funding from EPA. In addition to this project, the USEPA is funding the application of PipelineNet for five cities. These cities are New York, San Francisco, Seattle, Las Vegas, and Washington DC. The purpose of this 5-city project is to make water quality security tools available to utilities and provide support for this tool.

PipelineNet monitors and projects the fate and transport of potentially introduced contaminants in water distribution systems, particularly as related to use and application in an emergency response situation. It can be used for determining optimal placement of extraction and monitoring instruments, to help develop monitoring regimes for routine screening of distribution system water quality, and/or to predict/track the fate and transport of contaminants in a system in order to effectively respond to a purposeful or accidental contamination incident.

Understanding of water ageing (total net water age made up of multiple facility transport and detention times), and contaminant fate in water distribution systems is a high-priority water security need. This information is critical for planning and managing clean up and rehabilitation efforts, deciding when and how best to re-open contaminated systems, and developing strategies to detect purposeful or accidental contamination. Testing, evaluating, and upgrading the existing PipelineNet model provides an effective approach for addressing this immediate need. This is a very significant problem faced by the water utilities. This project will look into the feasibility of using hydraulic models for determining location and frequency of monitoring sites.

CHAPTER 2: APPROACH

The focus of this project was making PipelineNet functional for a new case study utility and investigating new functionalities of the model

For this project, the East Bay Municipal Utility District (EBMUD) in Oakland, California is the participating Utility. A portion of the EBMUD distribution system was used for the case application of PipelineNet. The study area represents 13% of the 122 pressure zones in the EBMUD distribution system.

TECHNICAL APPROACH

Development of PipelineNet for EBMUD

In order to make PipelineNet operative, water distribution data for the extended period simulation (EPS) model and GIS infrastructure data was provided by EBMUD. A fully calibrated EPS model represented the field conditions during the simulation period. The EPS model represents 24 hour, peak demand day conditions. The EBMUD study area is a fairly complex subsystem (it includes all pipes with diameter equal to and greater than 2 inches) of a larger EBMUD distribution system. Table 2.1 provides additional technical and location information about the area served. Figure 2.1 identifies the entire region served by EBMUD.

Table 2.1
Summary of EBMUD Water Distribution System Study Area

EBMUD Study Area - Model Summary	
Model Input	Quantity
Number of Junctions	16878
Number of Reservoirs	1
Number of Tanks	27
Number of Pipes	17997
Number of Pumps	62
Number of Valves	5
Pressure Zones	16
Minimum Pipe Diameter (inches)	2
Miles of Pipe Modeled	748

The development of the PipelineNet model for EBMUD involved the following steps:

- Convert steady state model to EPS model
- Perform calibration on integrated EPS model
- Load utility specific EPANET input file into PipelineNet
- Populate PipelineNet with utility specific GIS data
- Run scenarios, evaluate results

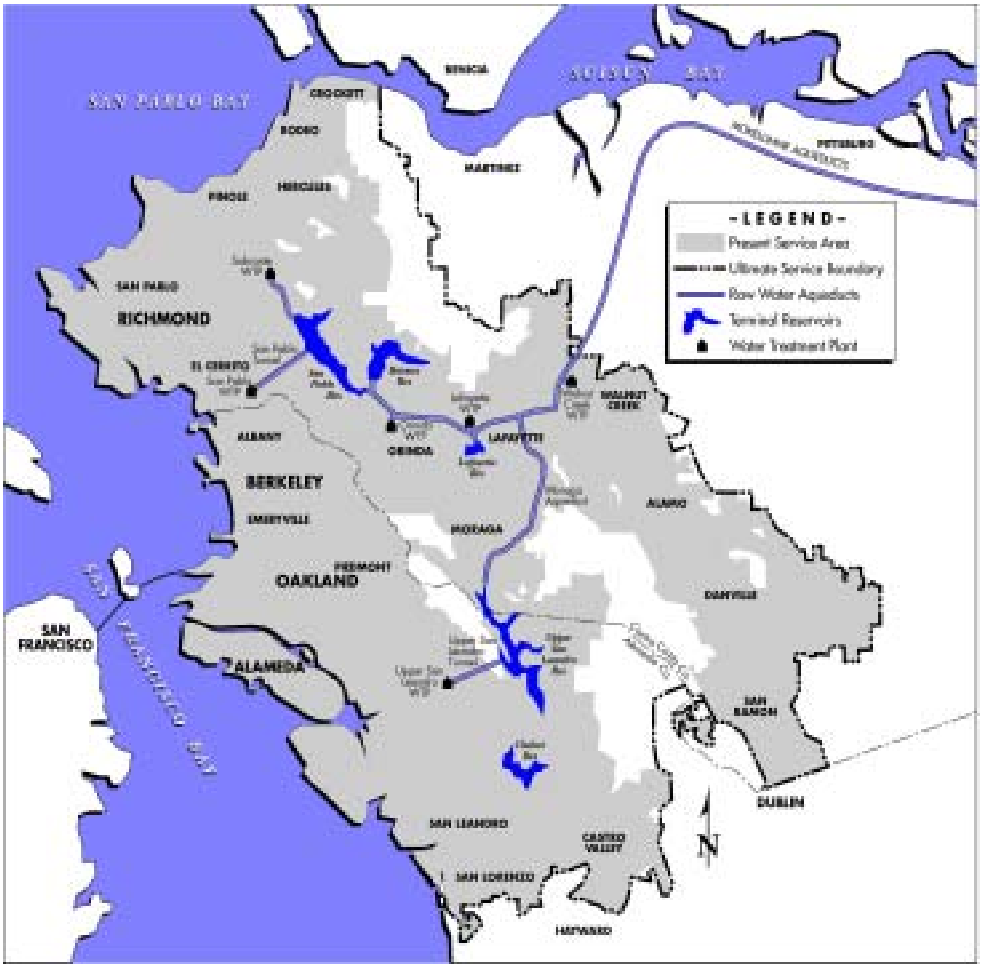

Figure 2.1 EBMUD Water Distribution Area.

Development of a Ranking Methodology for Monitoring Site Location

This section describes the development of a ranking/prioritization function for determining monitoring locations in a distribution system. The data used for this function consists of hydraulic model inputs, PipelineNet model outputs and GIS data. The ranking/prioritization function is based on a three-step hierarchical selection process to determine monitoring locations.

***Step 1 – Source Prioritization – Hydraulic Model Input Data*:** The first step in the ranking methodology is source prioritization. In a water distribution system every node (junction) is not available for monitoring. The source prioritization is performed by the delineation of unavailable or inaccessible areas for monitoring. This delineation is performed at the individual node (junction) level. The nodes that are generally not available for monitoring are:

- Nodes at the junction of two pipes with different diameter
- Nodes at the junction of pipes with different material
- Nodes associated with dead end pipes
- Nodes associated with crosses, tees, and other distribution facilities
- Nodes on transmission (backbone) pipes
- Nodes associated with a backflow-preventer
- Nodes which are physically inaccessible

Source prioritization is performed at the node (junction) level. The following procedure is established to eliminate non-available and in-accessible nodes.

- Initially, all nodes are considered available and are assigned a score of 1
- All the nodes, which are either not available or not accessible are assigned a score of 0
- Only nodes with score equal to 1 are considered for Step 2

Step 2 - Distribution System Response – PipelineNet Output: Hydraulic and water quality results determine the distribution system response. The distribution system response is determined at the pipe (link) level from an extended period simulation. The PipelineNet model output provides four sets of parameters (flow, velocity, pressure, concentration) upon which numerical scores are assigned. The following procedure is established to assign scores to pipes:

- The starting score for every pipe is 1.
- The scoring range is between 1 and 10 as shown in Table 2.2, where a score of 10 would indicate a higher level of concern.
- All distribution system response parameters (flow, velocity, pressure, water quality concentration) have equal weight regarding the assignment of scores.
- For any given parameter, the user can determine the distribution of scores over the parameter range. For example, a score range of 10 to 1 could be distributed over a flow range of 0.001 to 100 gpm. PipelineNet provides guidance for assigning scores but the user can select any score as per the requirement of the analysis. The breakpoints for assigning scores are controlled by the user.

Table 2.2
Distribution System Score Matrix

Parameter	Scores									
	1	2	3	4	5	6	7	8	9	10
Flow	High									Low
Velocity	High									Low
Pressure	High									Low
Concentration	Low									High

Step 3 – Critical Facilities and Population Density (GIS Layers): For this step, user defined buffer zones (polygons) are created around critical facility locations. In addition, areas of low, medium and high population density are delineated by the creation of polygons. Higher scores are assigned to pipes located within the critical facility buffer zones and high population density areas. The following procedure is established to assign scores to pipes:

- Pipes closest to the critical facilities will assigned a score of 10
- Pipes within high population density areas will be assigned a score of 10

The total score for each pipe is tabulated based on the values assigned to the matrices shown in Tables 2.2 and 2.3. These final scores are linked to the GIS pipeline layer. The user can identify areas where monitoring stations should be placed based on the display of pipes with high scores.

Table 2.3
Critical Facility and Population Density Score Matrix

Parameter	Scores									
	1	2	3	4	5	6	7	8	9	10
Hospitals	Far									Near
Schools	Far									Near
Population Density	Low									High

Development of Tools for Emergency Response, Mitigation and Normal Operation

In addition to the ranking/prioritization methodology incorporated into PipelineNet, three additional tools were developed as part of this project, to enhance its capability in the areas of emergency response, mitigation and normal operations. These three tools are described below.

Consequence Assessment Tool

The consequence assessment tool provides the ability to quickly identify and quantify the population, infrastructure and resources at risk from a contaminant event. For the contaminated area, this tool calculates:

- Total population at risk
- Number of taps contaminated
- Miles of pipe contaminated
- Total number of hospitals and beds for each hospital
- Total number of schools and student population

Isolation Tool

The isolation tool provides the ability to change the status (open or closed) of any pipe in the distribution system. After completing a water quality simulation and examining the contaminant distribution from the event, this tool would be used to close off one or more pipes to control the flow of water. The model would then be re-run, reflecting these new hydraulic conditions, and the output examined to determine if this mitigation step was successful in limiting the area of contamination.

Spatial Database Display Tool

PipelineNet can be used for determining optimal placement of extraction and monitoring instruments, to help develop monitoring regimes for routine screening of distribution system water quality, and/or to predict/track the fate and transport of contaminants in a system in order to effectively respond to a purposeful contamination incident.

Geographic Information System (GIS) software is capable of assembling, storing, manipulating, and displaying geographically referenced information or data identified according to their locations. For the drinking water industry, GIS allows large amounts of distribution system data to be compiled and users to query that data to identify areas in a distribution system meeting specified criteria. It is equivalent to plotting various data on individual see-through maps and laying those maps on top of each other so all data can be viewed together.

A tool that operates within the PipelineNet system has been developed for displaying model outputs and GIS layers. This tool contains a hierarchy of many layers. Each layer represents hydraulic or other features related to the water distribution system. This approach is similar to the one described in Stage 2 Disinfectants and Disinfections Byproducts Rule: Initial Distribution System Evaluation (IDSE) Guidance Manual for systems using GIS information (EPA 2001). Figure 2.2 shows the graphical user interface for the spatial database display tool contained within PipelineNet.

Figure 2.2 Interface for the spatial display of water distribution system and GIS data for application to Stage 2 Disinfectants and Disinfections Byproducts Rule: Initial Distribution System Evaluation (IDSE) Guidance Manual

CHAPTER 3: RESULTS AND DISCUSSION

The results of this study are described in this chapter. The main task for the project was Task 1 (location of monitoring points in the distribution system). New functionality was developed in PipelineNet to address this task and is discussed in detail in the paragraphs below.

The PipelineNet model in the extended period simulation (EPS) mode was adequate to address Task 2 (determining monitoring frequency in the distribution system) without modification. PipelineNet can be used to account for the timing and duration of peaks, valleys and other variabilities in contaminant concentrations that may occur spatially and temporally throughout a distribution system. Additional functionality was developed in this project in PipelineNet to isolate a contaminated area and study the effect of isolation on the flow regime.

As per the discussion with the project advisory committee (PAC), it was decided that it was preliminary to perform any new work on Task 3 (monitoring techniques and water quality parameters). A generally approved and peer-reviewed set of information was needed for performing a thorough analysis of this issue. The best effort relative to developing generally agreed to and peer-reviewed data is being performed by the Lawrence Livermore National Laboratory (LLNL) (a USEPA funded project). The completion of the LLNL project is late 2003 or early 2004. Therefore, it is the recommendation of the PAC that these findings be incorporated into PipelineNet when available.

EBMUD EPS MODEL CALIBRATION

Model calibration involved adjusting model parameters until an acceptable match between observed and simulated tank levels was reached. No calibration performance criteria exist in the USA. There is no industry consensus about the acceptable match threshold. AWWA has calibration guidelines (AWWA 1999) which were followed in this case study.

The model was calibrated by comparing the observed (SCADA data) and simulated (PipelineNet model) water level in 25 tanks located in the study area. A primary focus of the calibration was to match the shape of the observed water level in the tanks. The calibration of the model was performed for a 24-hour time interval for data measured on July 1, 2001. EBMUD provided a calibrated EPS model. To further enhance calibration, the pump characteristic curve was the only parameter needed to be changed to get a good comparison between simulated and observed tank levels. The flow value of the characteristic curve was changed to reflect the field conditions. Each pump was operating with time controls. The statistical comparison of the observed and simulated tank levels was performed for all tanks as shown in Table 3.1. The statistics list variation between simulated and observed values at each measurement location and for the network as a whole. The statistics listed for each measurement location are:

- Number of observations
- Mean of the observed values
- Mean of the simulated values
- Mean absolute error between each observed and simulated value
- Root mean square error (RMSE)

The smaller the RMSE, the better the performance of the model. There are no specific guidelines published by AWWA for statistical analysis of the calibration results. The RMSE for the entire network is 1.392 feet indicating a good comparison between observed data and simulated results. The mean error for the entire network was 1.0 foot.

Table 3.1
EBMUD calibrated EPS model results

alibration Statistics for Head					
Location (Tank #)	# of Obs.	Observed Mean Elevation (ft)	Computed Mean Elevation (ft)	Mean Error	RMS Error
144	24	1193.31	1194.18	0.872	0.984
2072	24	1039.75	1040.50	0.776	1.006
4097	24	942.81	943.27	0.458	0.581
4098	24	943.25	943.90	0.760	1.085
10860	24	742.70	742.53	0.527	0.637
14307	24	948.86	949.17	0.306	0.432
17500	24	632.93	633.05	0.351	0.451
19340	24	637.46	636.97	0.492	0.561
19488	24	945.41	942.82	2.593	2.815
19489	24	944.18	943.88	0.681	0.787
26849	24	546.11	543.73	2.600	3.435
26850	24	540.23	540.06	0.293	0.340
26851	24	538.92	538.01	0.903	0.988
31403	24	538.59	538.60	0.138	0.190
31723	24	745.56	745.22	0.370	0.435
32059	24	944.55	945.36	0.805	0.880
32188	24	1149.04	1148.75	0.533	0.673
34188	24	738.51	735.76	2.754	3.070
34189	24	737.72	739.73	2.007	2.184
35510	24	1001.77	1002.39	0.617	0.699
35644	24	1146.37	1147.46	1.090	1.158
45622	24	349.10	348.63	0.691	1.211
45623	24	350.10	349.15	0.943	1.112
45638	24	369.44	370.65	1.212	1.309
178082	24	743.11	743.11	0.599	0.701
Network	600	776.39	776.27	0.935	1.392
Correlation Between Means: 1.000					

LOCATION OF MONITORING STATIONS

The optimal location of monitoring stations is a complex issue and is dependent on many interlinked parameters. A ranking/prioritization tool was developed in PipelineNet and works with an extended period simulation model. Figure 3.1 shows a hypothetical study area water distribution system that served as the starting point for the selection of the monitoring locations. The following discussion relates to a hypothetical example where parameters and values are randomly chosen to demonstrate the applicability of PipelineNet. The use of the tool is demonstrated with the EBMUD EPS model using the following options:

- For the source prioritization step, all the dead end pipes were eliminated from consideration. This reduced the number of pipes available for monitoring from 17997 to 14938.
- For the distribution system response step, flow, velocity, and pressure were examined at the 9th hour of simulation. Other time periods can be evaluated as well.
- For any given parameter (flow, velocity, pressure) in the distribution response step, the allocation of scores is determined by the user using one of the three methodologies as explained below:

    - **Natural Breaks**: This method identifies break points between different classes of a parameter using a statistical formula (Jenk's optimization). This method is rather complex, but basically the Jenk's method minimizes the sum of the variance within each of the classes. Natural Breaks finds groupings and patterns inherent in the data.
    - **Equal Interval**: The equal interval method divides the range of parameter values into equal sized sub-ranges. Then the features are classified based on those sub-ranges.
    - **Quantile**: In the quantile classification method, each parameter class contains the same number of features. Quantiles are best suited for data that is linearly distributed; in other words, data that does not have disproportionate numbers of features with similar values.

The following options were used to create a scoring matrix and are shown in Figures 3.2, Figure 3.3, and Figure 3.4:

- Flow (cfs) – Quantile
- Velocity (fps) – Natural Breaks
- Pressure (psi) – Equal Interval

Note: Some utilities may choose to use the "Natural Breaks" methodology to categorize the parameter data due to very few pipes having extremely large flows, and very few pipes having very little flow.

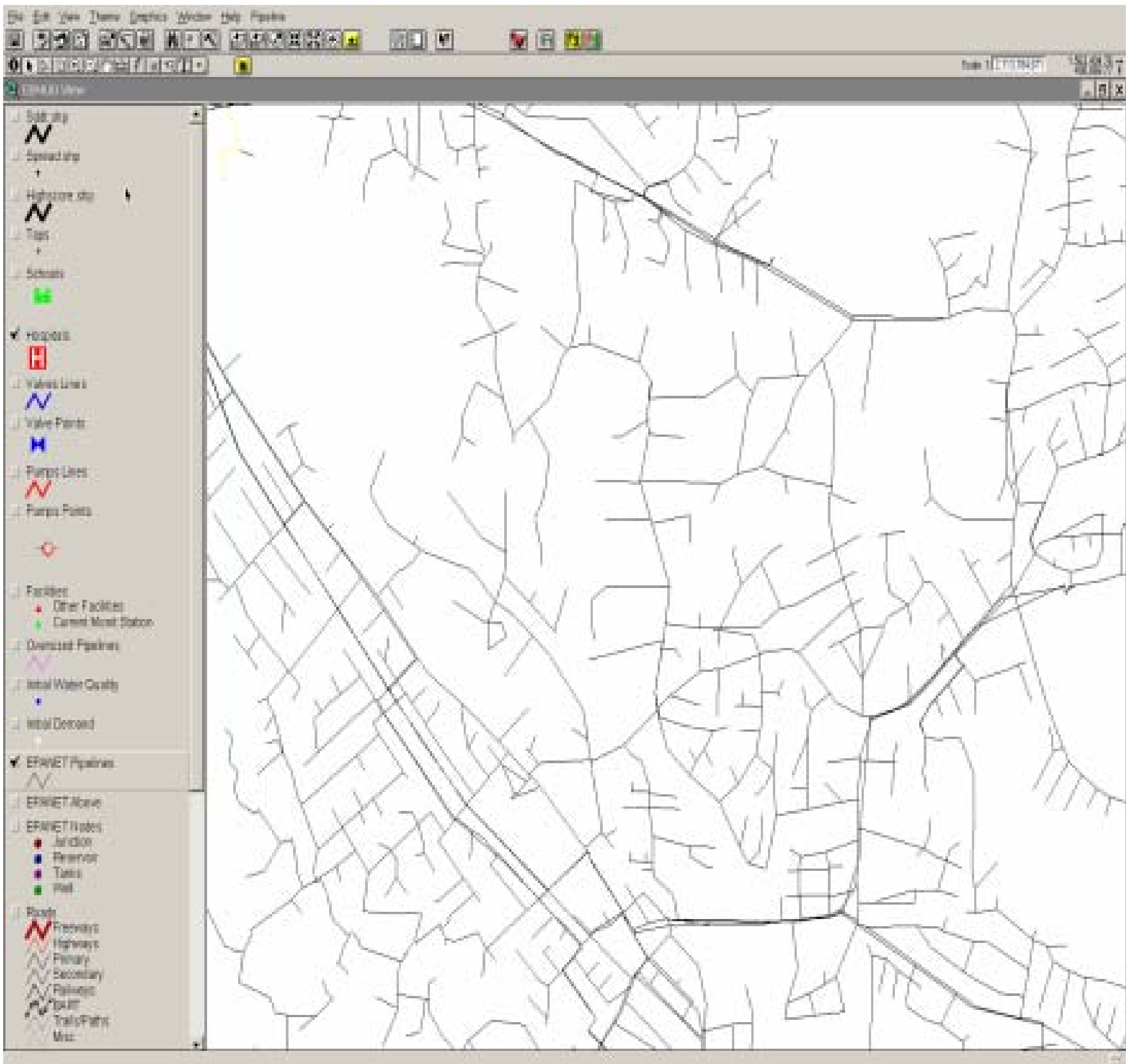

Figure 3.1 Hypothetical water distribution system showing pipelines.

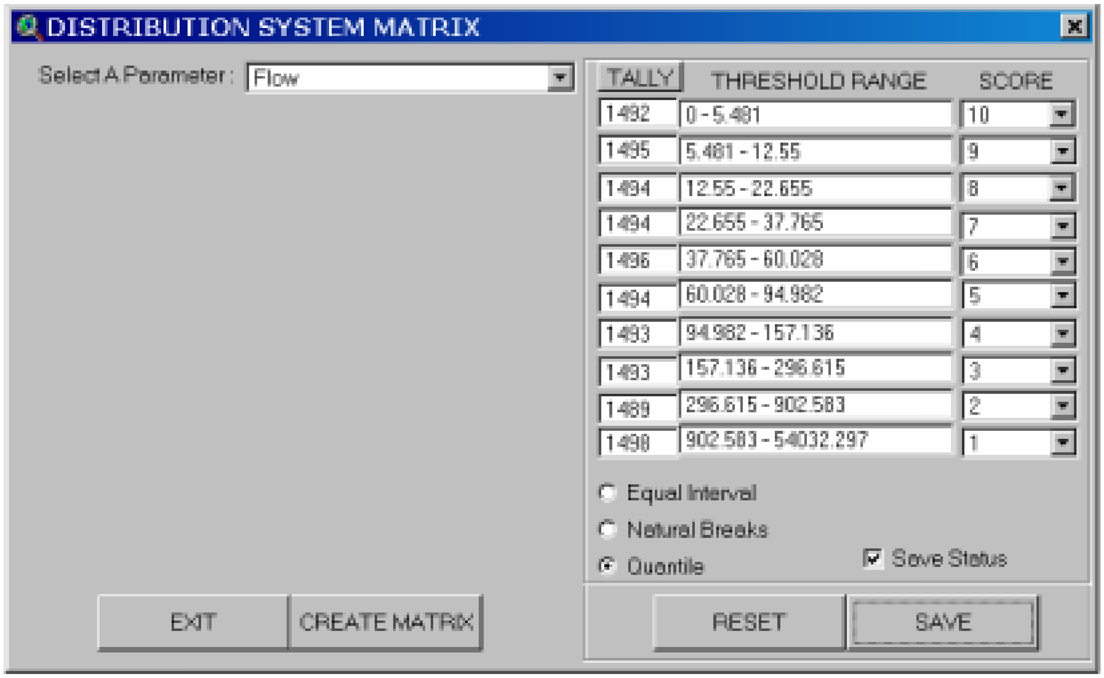

Figure 3.2 Distribution system response matrix for the flow parameter

The scoring matrices for flow, velocity, and pressure provide an example of this tool's functionality. The user has the flexibility to select one of the three options (quantile, equal interval, natural breaks) for any parameter. The threshold range values used in this example are only for guidance. The user can override any value that is output from the three options. The scores ranged from 1 – 10, where low velocity, pressure and flow values received high scores, indicating that these areas may be where poor water quality might occur and that monitoring would be necessary. Based on this scheme, the highest score assigned to any one pipe would be 30. Factors could also be weighted for different risk scoring, although they were not in this example.

Based on the example hypothetical scoring matrices, Figure 3.5 shows highlighted areas that represent pipes with high scores (score > 27). These areas are candidates for locating monitoring stations. This figure also shows how these high scoring areas are distributed within each pressure zone. These areas can further be refined by overlaying critical facilities (schools and hospitals) as shown in Figure 3.6. Figures 3.5 and 3.6 show snapshots for one time period (hour 9 of the simulation). Multiple layers for different time periods can be created and overlain to get a representative layer of monitoring stations for a 24-hour period. The simulation time duration is user defined. The choice of 24 hour simulation for the study area was based on the input data available. PipelineNet can run for more than 24 hours if data is available.

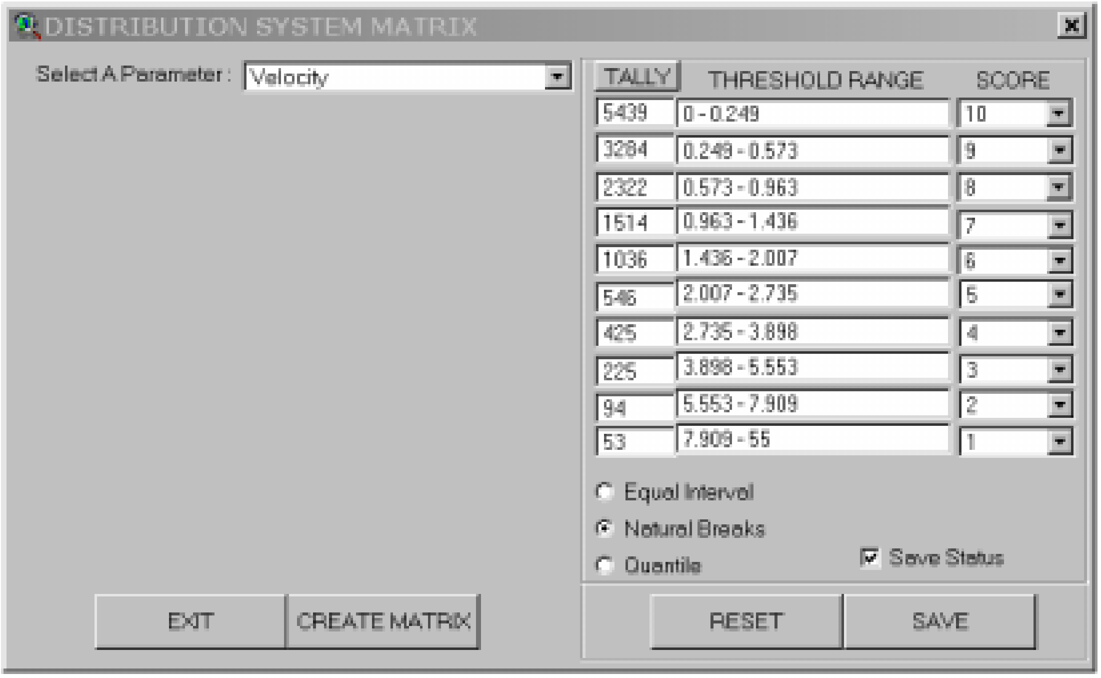

Figure 3.3 Distribution system response matrix for the velocity parameter.

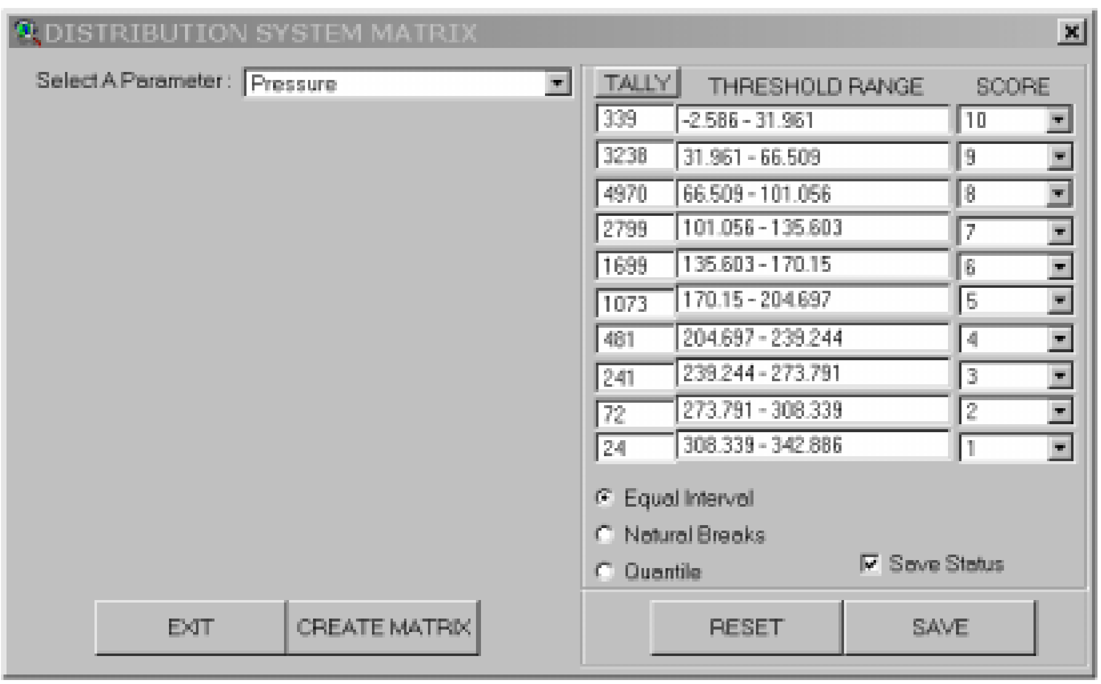

Figure 3.4 Distribution system response matrix for the pressure parameter.

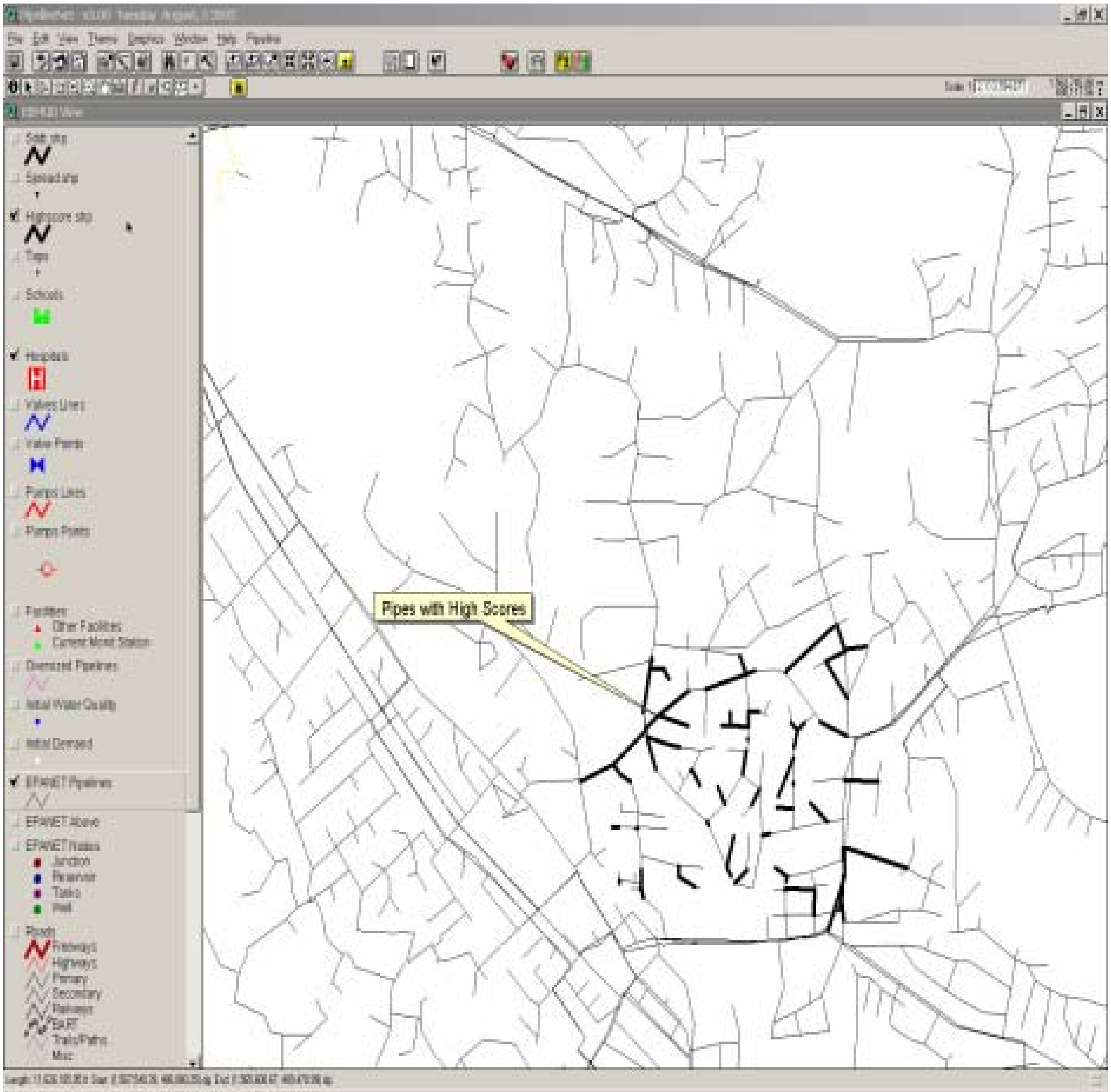

Figure 3.5 Hypothetical system showing areas (bold pipelines) with high scores (> 27).

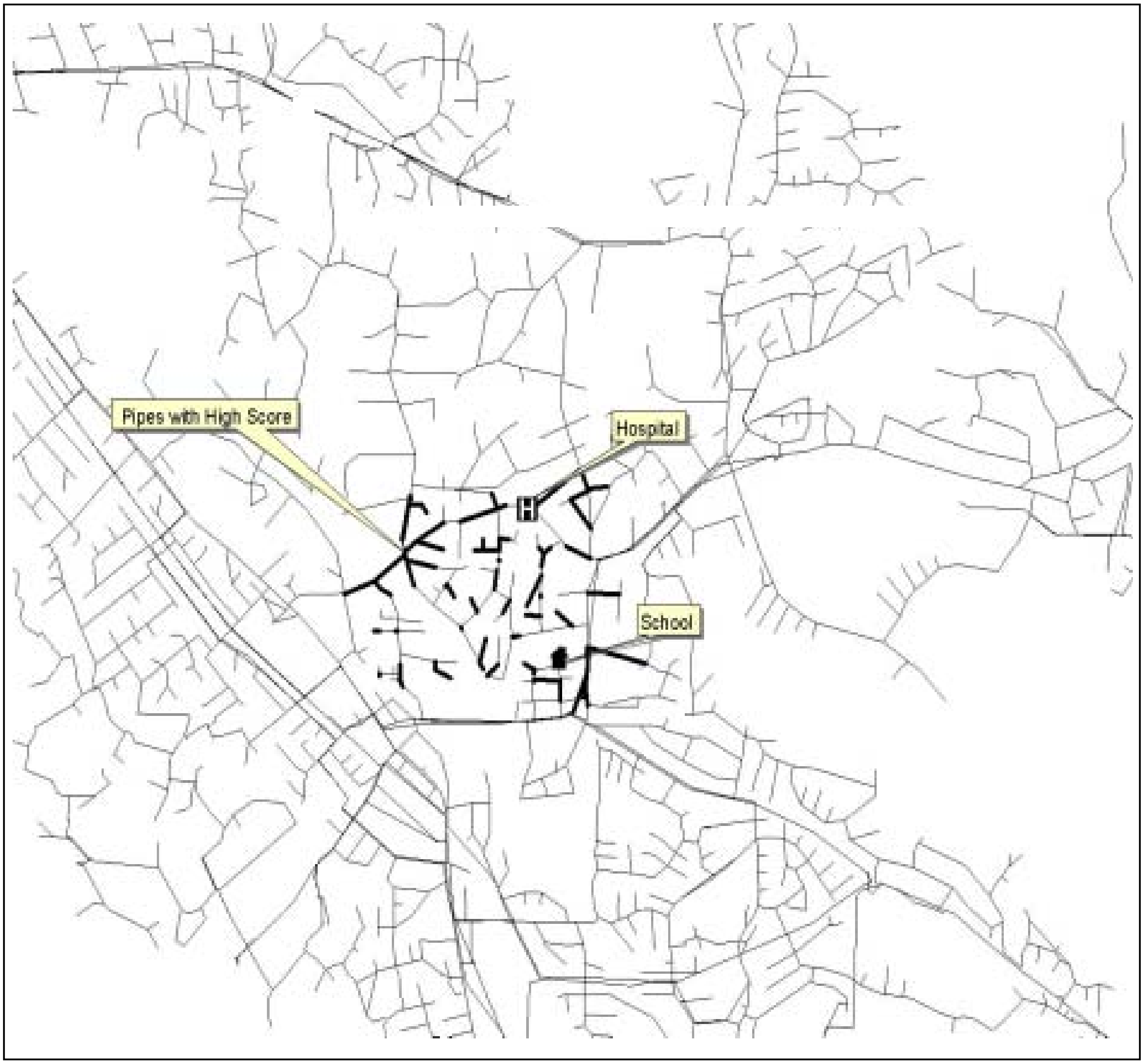

Figure 3.6 Hypothetical system showing high score areas (> 27) overlain with hospitals and schools.

CONSEQUENCE ASSESSMENT

Consequence assessment (population, taps, length of pipeline, number of schools and hospitals at risk) of an incident is performed in PipelineNet by a point and click interface. The results for the user-selected area of the concern are displayed in the table shown in Figure 3.7. Figure 3.7 shows the spread of contamination at the 9th hour of simulation from the indicated source and the critical facilities and population impacted by the contamination.

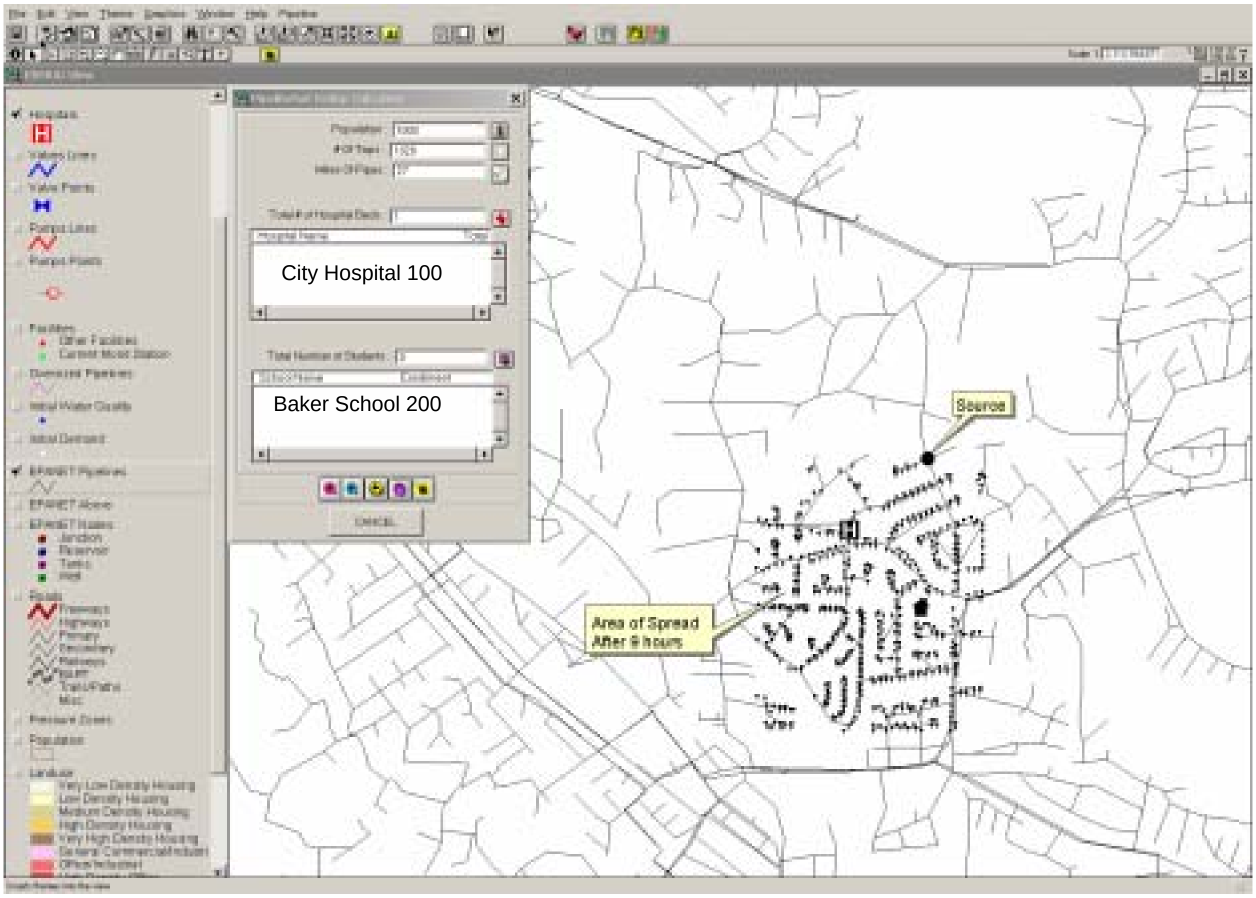

Figure 3.7 Output from the Consequence Assessment Tool.

POST INTRUSION ISOLATION

The Isolation Tool in PipelineNet performs post intrusion isolation. Selecting the pipe with the cursor shows Pipe ID and its status (Figure 3.8). The status is changed from OPEN to CLOSED by selecting from the pull down menu. Clicking the APPLY button will update the PipelineNet GIS data and clicking on UPDATE INPUT FILE will update the hydraulic model input file. A new simulation can be performed with updated pipe status to see the effect of isolating a section of the water distribution system.

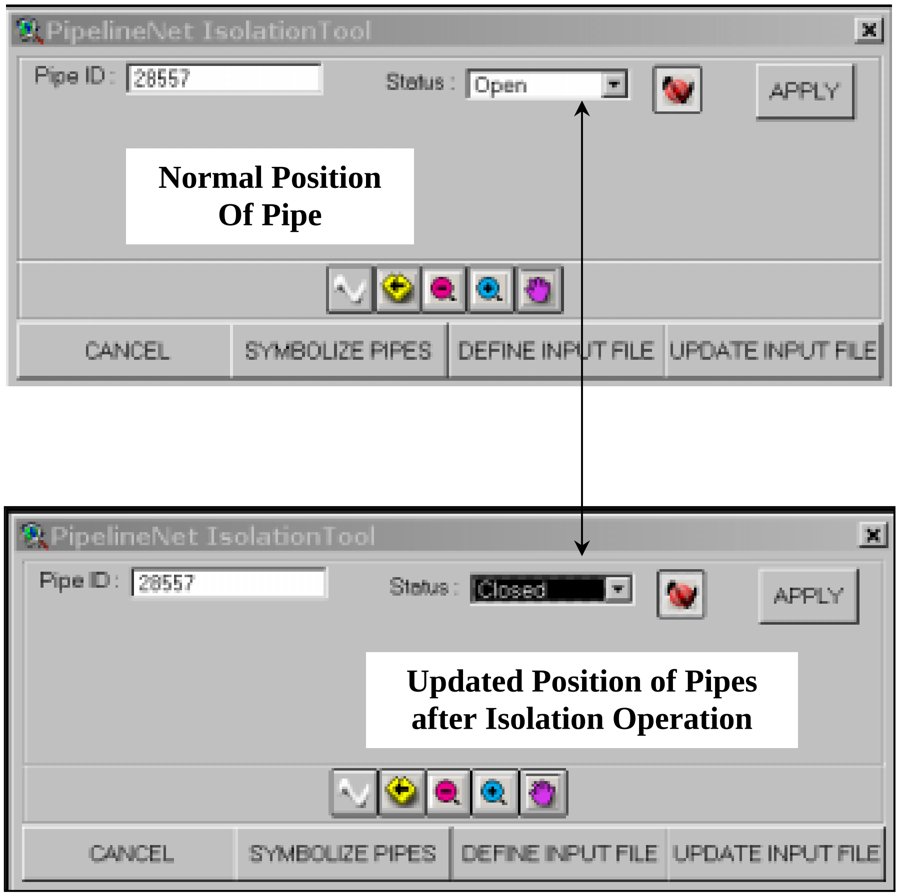

Figure 3.8 Operation of Isolation Tool in PipelineNet.

SPATIAL DATABASE DISPLAY

PipelineNet, being a GIS based model, can overlay model output and features with various properties. Once data is properly integrated into a GIS application, users can query the data to locate areas, which meet several criteria. These criteria are dependent on the objective. The Spatial Database Display Tool of PipelineNet has nineteen criteria from which to choose. For illustration purposes, Figure 3.9 shows the display of three criteria: oversized pipes (diameter

>30”), current monitoring locations, and low velocity (velocity < 0.001 FPS) pipes. Users can select any combination of the 19 criteria.

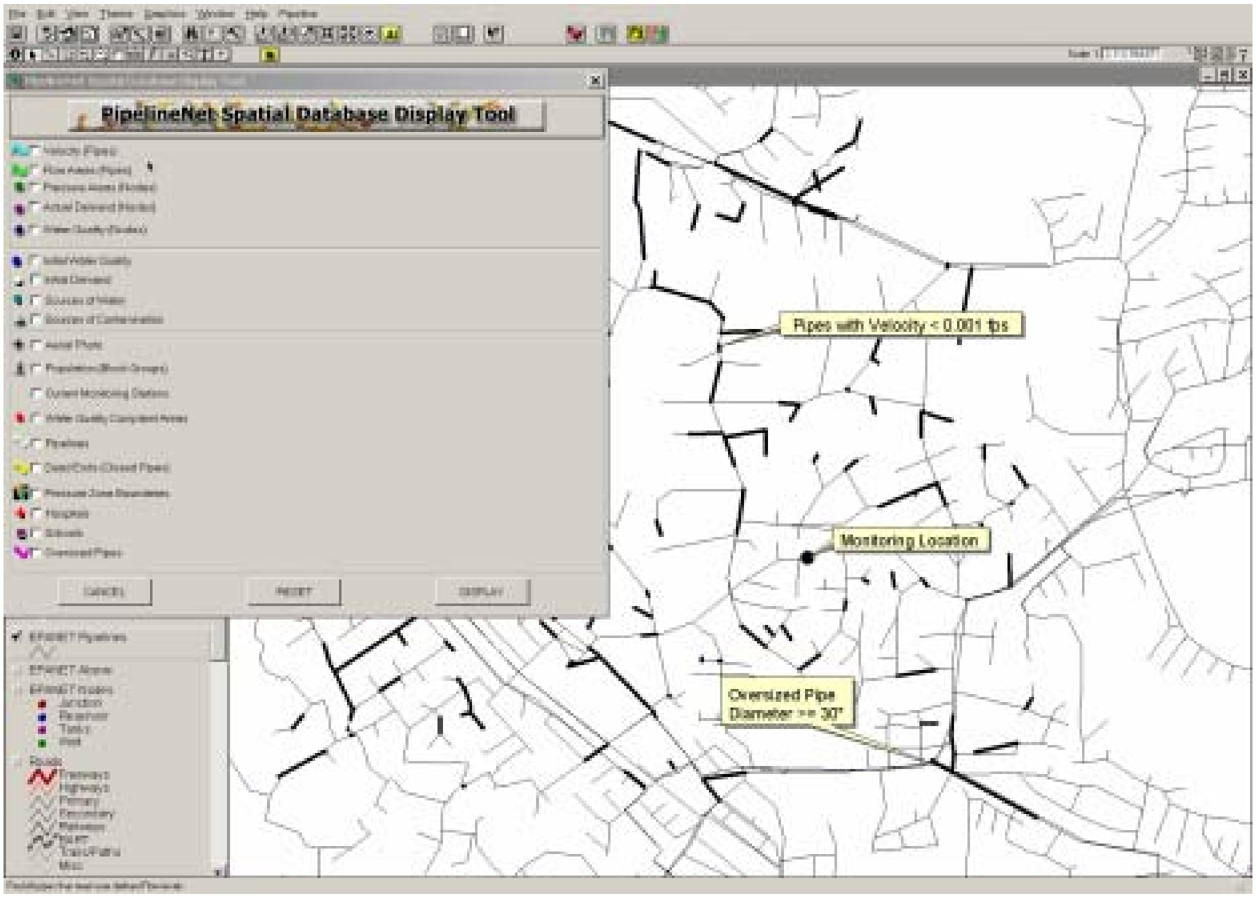

Figure 3.9 Display of low velocity pipes, oversized pipes, and current monitoring stations using the Spatial Database Display Tool

PIPELINENET CONTAMINANT DATABASE

PipelineNet has a database of 62 chemical – biological contaminants. These contaminants are divided into six categories:

- Chemical Warfare Agents
- Toxins
- Protozoa
- Viruses
- Bacteria & Rickettsiae
- Toxic Industrial Chemicals

All of the physical, chemical, and biological properties for these contaminants were compiled from open literature in a report prepared by Dr. Rolf A. Deininger, University of

Michigan School of Public Health. The project sponsor (EPA) considers the compilation of the specific agent properties as sensitive. Until a final decision about the release of the detailed information, the contaminant database only contains the following information:

NAME	Name of Agent
TYPE	Type of Agent
HALF LIFE	Half-life in days related to the high medium and low decay rates.
DECAY RATE	A guidance decay rate of high, medium, and low rate based on values in literature.

In PipelineNet, either half-life or decay rate can be specified. At this time, PipelineNet does not include the effects of inherent bio-films in the distribution system.

CHAPTER 4: SUMMARY AND CONCLUSIONS

Purposeful and accidental contamination is a potentially significant problem faced by water utilities. The availability of a water distribution system model would allow water utilities to identify, monitor, and track contaminants in their water distribution system and to react more effectively to a contamination incident. The results of this case study show how PipelineNet can be used to simulate the fate and transport of a contaminant introduced into the distribution system and the use of tools to quickly assess the consequences of this event.

In addition, using the PipelineNet inputs, outputs and GIS layers, a methodology was developed and integrated into PipelineNet to identify potential areas for the location of monitoring stations. The placement of sensors that can send data to the PipelineNet model would be a powerful capability in the rapid response to a potential terrorist threat.

BENEFITS FOR WATER SUPPLY COMMUNITY

PipelineNet has many benefits that will help water utilities to meet their normal operations and also to respond to intentional and accidental contamination:

- EPANET hydraulic model - includes all the functionality of EPANET and GIS
- PipelineNet is a GIS based system – allows for map display and overlay of model output
- Ranking/prioritization Tool - assists in the location of monitoring stations
- Consequence Assessment Tool – calculates population and infrastructure at risk from an event
- Isolation Tool – evaluate the effectiveness of mitigation measures to reduce the spread of contamination (closing pipes)
- Spatial Display Database Tool – helps in regulatory compliance as described in Initial Distribution System Evaluation (IDSE) Guidance
- Normal Operation – simulates hydraulics (flow) and water quality (concentration, tracing, and ageing)
- Emergency Response and Planning – simulates water quality for chemical and biological agents

PIPELINENET AVAILABILITY

The availability of a water distribution system model would allow water utilities to identify, monitor, and track contaminants in their water distribution system and to react more quickly to a terrorism incident. The Federal Emergency Management Agency (FEMA) in conjunction with the Technical Support Working Group (TSWG) funded the original development of PipelineNet (http://www.tswg.gov/tswg/ip/PipelineNetTB.htm). PipelineNet is a public domain model and is available through the US Environmental Protection Agency (EPA). The address for the EPA project manager is given below.

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202-564-3890, email: mccormack.kevin@epa.gov

In the future, PipelineNet will also be available for download from the WATERISAC (http://www.waterisac.org), a member's only secure and security-oriented web site. PipelineNet is a user-friendly system. It requires knowledge of hydraulic modeling and basic GIS functions. The development of the PipelineNet model involves the following steps:

- Convert steady state model to EPS model
- Perform calibration on integrated EPS model
- Load utility specific EPANET input file into PipelineNet
- Populate PipelineNet with utility specific GIS data
- Run scenarios, evaluate results

The time and effort needed to get PipelineNet up and running is dependent on the condition and status of a utility's hydraulic model and GIS data. If these two components are fully developed, then the PipelineNet application can be made operational in a short time frame (3-6 months). Additional time and effort is required if the model is not fully developed and GIS data needs to be produced.

FUTURE RECOMMENDATIONS

The following tasks are recommended to enhance the existing capabilities of PipelineNet and make it more useful to the water utilities:

Contaminant database - The PipelineNet database contains 62 chemical-biological agents. Complete data for some agents was not available. There are potential new sources of more complete information (e.g., EPA State of Knowledge Report, and Lawrence Livermore National Laboratory work), which may be available soon. A link from PipelineNet to these sources, or incorporation of these new data into PipelineNet would increase the power and usefulness of PipelineNet. Some of these new sources may include monitoring techniques for the chem-bio agents, which would also be very useful.

Back tracing - Back tracing identifies source(s) of contamination once they are detected by a monitoring station located within the distribution system. A back tracing function will greatly aid in responding to a deliberate or accidental release by identifying the area and display of water flows from single/multiple points to the monitoring location. Some work is ongoing to further develop this capability, which would be useful to incorporate into PipelineNet.

Time of travel - This calculation will help in identifying the time for the leading edge, peak concentration and trailing edge of a contaminant plume to reach any node in the system. This information would allow a warning to be issued to a critical facility about the arrival time of the contaminant.

Decontamination - The two primary elements of clean up and decontamination are treatment of the contaminated pipelines and disposal of the contaminated water. Development of database of technologies to clean chem-bio agents in contaminated water and identification of disposal of the treated water improve the response in case of a release of contaminants in the water distribution system.

Conversion from ARCVIEW 3.2 to ARCGIS - The current version of PipelineNet is based on ARCVIEW 3.2; however, utilities are upgrading to ARCGIS and adopting the ARC FM

WATER data model. The conversion of PipelineNet to ARCGIS and the ARC FM WATER data model will keep it current with the evolution of GIS technology.

Linkage of PipelineNet to SCADA Data – Linking PipelineNet with a utility's SCADA system allows real-time updates of the hydraulic model's input conditions (i.e., tank levels and demand patterns).

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ABBREVIATIONS

AWWA	American Water Works Association
AwwaRF	Awwa Research Foundation
cfs	Cubic Feet per Second
D2BP	Disinfectants and Disinfections by Products
EBMUD	East Bay Municipal Utility District
EPA	Environmental Protection Agency
EPS	Extended Period Simulation
FEMA	Federal Emergency Management Agency
fps	Foot per second
GIS	Geographical Information Systems
gpm	Gallons per minute
IDSE	Initial Distribution System Evaluation
LLNL	Lawrence Livermore National Laboratory
PAC	Project Advisory Committee
P.E.	Professional Engineer
Psi	Pounds per Square Inch
RMSE	Root Mean Square Error
SCADA	Supervisory Control and Data Acquisition
TSWG	Technical Support Working Group
US	United States
WATERISAC	Water Information Sharing & Analysis Center

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